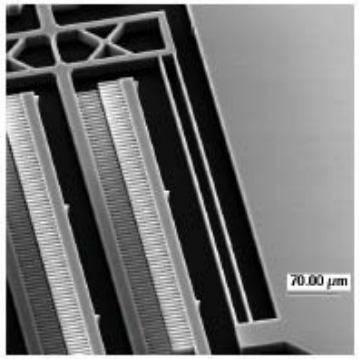
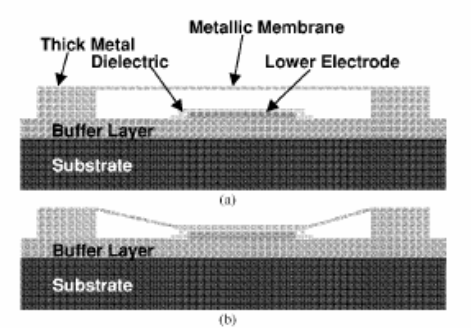
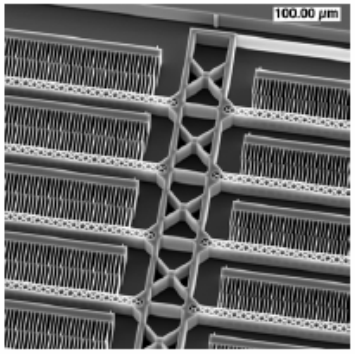
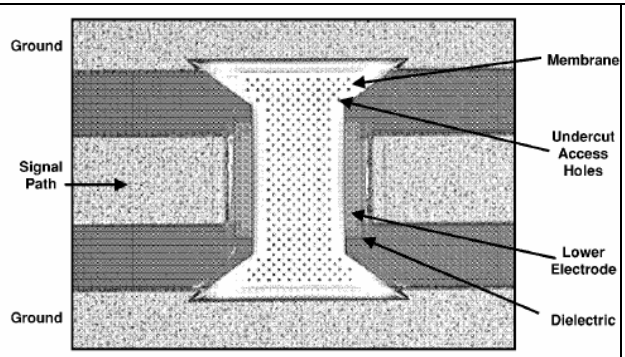
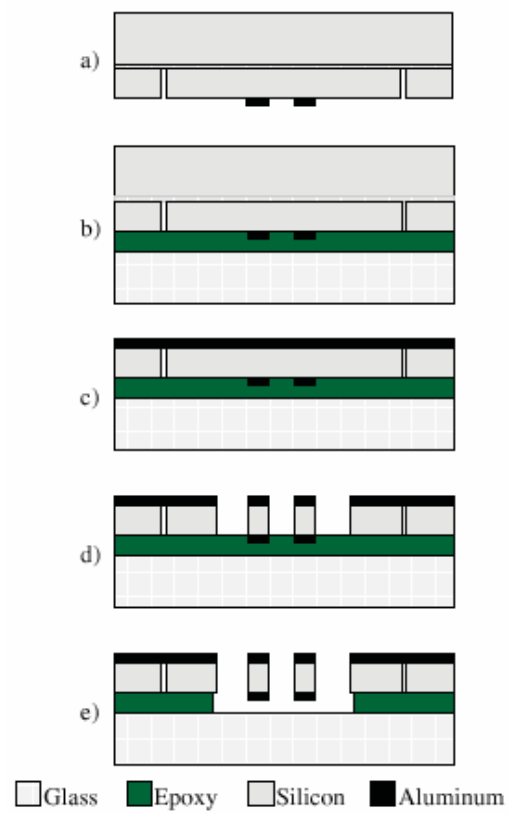
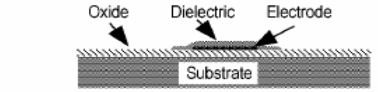
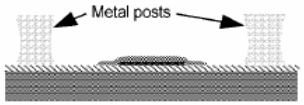
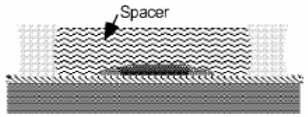
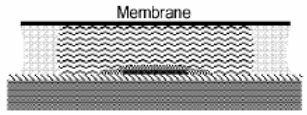
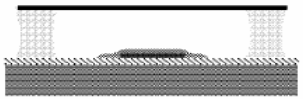
Example of MEMS Device Treasure Hunt: Tunable capacitor/Tuning ratio
By Xue'en Yang

	Device #1	Device #2	Device #3
Reference(s)	• Borwick, R.L., III, Stupar, P.A., DeNatale, J., Anderson, R., Chialun Tsai, Garrett, K. and Erlandson, R., "A high Q, large tuning range MEMS capacitor for RF filter systems," *Sensors and Actuators A (Physical)*, v A103, n 1-2, 15 Jan. 2003, p 33-41 • Borwick, R.L., III, Stupar, P.A., DeNatale, J., Anderson, R., Chialun Tsai, and Garrett, K., "A high Q, large tuning range, tunable capacitor for RF applications," *MEMS 2002*, Las Vegas, NV, USA, pp 669-672	Goldsmith, C.L., Malczewski, A., Yao, Z.J., Chen, S., Ehmke, J. and Hinzel, D.H., "RF MEMS variable capacitors for tunable filters," *International Journal of RF and Microwave Computer-Aided Engineering*, 1999. 9: p. 362-374.	…
Affiliation(s)	• Rockwell Scientific Company	• Raytheon Systems Corporation	• …
Device description	• Electrostatic comb drive with double beam suspension as shown in this SEM micro graph:  • The comb fingers form the many capacitors in parallel • Applied DC voltage changes the overlapped areas of the fingers and hence the value of the total capacitance • Below is a SEM micro graph showing the etched comb fingers:	• Bistable metallic membrane suspending over an insulated electrode • A DC voltage applied between the membrane and the electrode snaps down the membrane and the change of the gap results in change of the capacitance between the membrane and the electrode • The schematic below shows the device before and after actuation:  • A device top view is shown here:	• …

			
Fabrication technology	Bulk micromachining is used • Use SOI (silicon on insulator) wafers • Epoxy bond of silicon to glass • Comb fingers are etched with DRIE (deep reactive ion etch) technique • Fabrication process is shown below: 	Surface micromachining is used • Use high resistivity silicon as substrate • Thermally grown oxide is used as the buffer layer • Nitride is used as dielectric • Aluminum is used as metal posts and membrane • Fabrication sequence is shown below:  (a) Oxide deposition, electrode, dielectric deposition and patterning  (b) Metal posts deposition and patterning  (c) Spacer coating and patterning  (d) Membrane deposition and patterning  (e) Removal of the spacer material by dry etching	• …

Pros of approach	• Use double beam suspension to increase resistance and hence reduce sensitivity to vibration • Use double-sided metallization to reduce stress caused by deposition of metal • Use epoxy to bond silicon to glass to reduce cost and simplify process; oxygen plasma release of structure does not cause post-release stiction	• Simple surface micromachining processes and simple operation • Fast and robust switching of capacitance • Refractory metal is used as bottom electrode to provide good conductivity and smooth surface to minimize the air gap and hence maximize the close capacitance • Process is IC compatible	• …
Cons of approach	• Process involves front to back alignment • Device might subject to low break-down because of large areas and small gap • Process is not IC compatible	• Bistable nature of the device allows only digital tuning • Residual stress in aluminum during deposition and post release will cause membrane to warp and hence initial capacitance and pull-in voltage can vary • Use of high resistivity silicon substrate is more expensive while the substrate loss is higher compared to glass	• …
Value of reported metric	• Analog tuned • Tuning ratio is 8.4:1 for 8V actuation voltage • Q is above 100 for frequencies below 700 MHz	• Digital tuned • Tuning ratio of single device is 70-100:1 for 30-50 V actuation voltage • Q is 20 at 1 GHz	• …
Measurement method	A HP network analyzer is used to measure the capacitance and the S parameters	S-parameter measurements were performed using a Wiltron 37279 vector network analyzer and a Cascade Summit 10000 RF probing system.	…
Confidence in results (1- 5) and why	4 – device yield is not reported; low break-down voltage might limit operation range	4 – device yield is not reported; stiction could be a problem during operation	…
Comments	The device has high analog tuning ratio and relatively low actuation voltage compared to other literature found. Although device with higher tuning ratio exists, in terms of overall performance, this is the best device so far.	A tunable capacitor with desirable tuning configurations can be achieved by using a network of this switching capacitor device. But the overall Q is lowered as a result of parasitic effects. Also, the actuation voltage of this device is too high to be useful in portable communication applications.	…